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Term: L26 and L8

Display: 10 **Documents in Display Format:** - **Starting with Number** 1

Generate: ○ **Hit List** ◉ **Hit Count** ○ **Side by Side** ○ **Image**

Search Clear Interrupt

Search History

DATE: Friday, March 04, 2005 Printable Copy Create Case

Set Name side by side	**Query**	**Hit Count**	**Set Name** result set
	DB=PGPB,USPT,USOC,EPAB,JPAB,DWPI,TDBD; PLUR=YES; OP=ADJ		
L29	L26 and L8	0	L29
L28	L26 and L1	0	L28
L27	L26 and L2	0	L27
L26	L25 and (pixel near data)	87	L26
L25	L23 and (medical near3 image$)	677	L25
L24	L23 and L17	2	L24
L23	382/128,131,274.ccls.	2721	L23
L22	L21 and (pixel or picture$ near3 image data)	3	L22
L21	L17 and (medical near3 image$)	21	L21
L20	L17 and L8	0	L20
L19	L17 and L2	0	L19
L18	L17 and L16	0	L18
L17	600/415,621,625.ccls.	174	L17
L16	L15 and (extract$ same image$)	39	L16
L15	L14 and (image$ near3 database$)	149	L15
L14	L10 and (browser or internet)	3210	L14

L13	L10 and L8	0	L13
L12	L10 and L2	0	L12
L11	L10 and L1	0	L11
L10	707/10,104.ccls.	4473	L10
L9	"physiologic knoledge engine" and "medical image"	0	L9
L8	"encoder engine" and (convert$ same image$ or pixel data)	17	L8
L7	"decoder engine" and (extract$ same image$ near3 pixel data)	1	L7
L6	L4 and L1	1	L6
L5	L4 and L2	3	L5
L4	"transfer engine" and (image$ or picture$ or document$)	452	L4
L3	L2 and L1	1	L3
L2	"converter engine"	1105	L2
L1	"decoder engine"	80	L1

END OF SEARCH HISTORY

Hit List

Clear | Generate Collection | Print | Fwd Refs | Bkwd Refs
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Search Results - Record(s) 1 through 3 of 3 returned.

☐ 1. Document ID: US 6801034 B2

Using default format because multiple data bases are involved.

L22: Entry 1 of 3 File: USPT Oct 5, 2004

US-PAT-NO: 6801034
DOCUMENT-IDENTIFIER: US 6801034 B2

TITLE: Method and apparatus of acquiring large FOV images without slab-boundary artifacts

DATE-ISSUED: October 5, 2004

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Brittain; Jean Helen	Pewaukee	WI		
Pauly; John Mark	Redwood City	CA		

US-CL-CURRENT: 324/309; 324/318, 600/415, 600/425

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw. De

☐ 2. Document ID: US 6794869 B2

L22: Entry 2 of 3 File: USPT Sep 21, 2004

US-PAT-NO: 6794869
DOCUMENT-IDENTIFIER: US 6794869 B2

TITLE: Moving table MRI with frequency-encoding in the z-direction

DATE-ISSUED: September 21, 2004

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Brittain; Jean Helen	Menlo Park	CA		

US-CL-CURRENT: 324/309; 324/306, 324/307, 324/318, 600/410, 600/415

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw. De

☐ 3. Document ID: US 6560476 B1

L22: Entry 3 of 3 File: USPT May 6, 2003

US-PAT-NO: 6560476
DOCUMENT-IDENTIFIER: US 6560476 B1
**** See image for Certificate of Correction ****

TITLE: Evaluating disease progression using magnetic resonance imaging

DATE-ISSUED: May 6, 2003

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Pelletier; Jean Pierre	St- Lambert			CA
Pelletier; Johane	St-Lambert			CA
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Raynauld; Jean-Pierre	Boucherville			CA
Barthiaume; Marie-Josee	Ville Mont-Royal			CA
Beaudoin; Gilles	St. Lambert			CA
Godbout; M. Benoit	Montreal			CA
Kauffmann; M. Claude	Montreal			CA

US-CL-CURRENT: 600/410; 382/130, 600/415

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw De

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Terms	Documents
L21 and (pixel or picture$ near3 image data)	3

Display Format: - Change Format

Previous Page Next Page Go to Doc#

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L22: Entry 1 of 3 File: USPT Oct 5, 2004

DOCUMENT-IDENTIFIER: US 6801034 B2
TITLE: Method and apparatus of acquiring large FOV images without slab-boundary artifacts

Brief Summary Text (12):
Yet another aspect of the invention includes a computer program having a set of instructions executed by a computer to control a medical imaging scanner and create images across scanning boundaries without significant boundary artifacts. The computer is caused to select an FOV spanning an area greater than a predefined optimal image area of the medical imaging scanner, apply an RF pulse to excite a region of interest, and apply magnetic field gradients to encode the region of interest in a first direction. The volume of interest is limited in the direction of table motion either by using a slab-selective RF pulse or by acquiring the data in such a way that an acquisition filter can be used to restrict the spatial extent. Three-dimensional image data can then be acquired in the first direction as a subset of a second and third direction for each table movement. The computer then causes a patient table to move an incremental step with respect to the medical imaging scanner, and repeat the image data acquisition in the first direction for he remaining two directions until sufficient data is acquired across the entire FOV. An image can be reconstructed without slab-boundary artifacts after aligning anatomical data in the first direction.

Detailed Description Text (9):
Referring to FIG. 2, a data acquisition and processing technique, in accordance with the present invention, is shown schematically. FIG. 2 illustrates one embodiment of the present invention for acquiring data. In this embodiment, the table is step-wise incremented 15 times with data acquisitions 106 in 16 table positions along the desired FOV. Each of the table increments are of equal distance .DELTA..sub.z. A patient 100 is positioned on a moveable table 102, which moves fore and aft 104 within the MRT scanner 10 with respect to the magnet and the optimal imaging area 108 of the MRI scanner. The desired FOV 110 is substantially larger than the optimal imaging area 108, which is generally. larger than a selected slab thickness 112. As previously discussed, the table motion in this simplified example is in the z direction. Magnetic field gradient waveforms arc designed to encode four k.sub.z -k.sub.y subsets (N.sub.wf =4) with a total of 16 table positions and data acquisition sets 106. At each table position 1-16, there are four data acquisitions encoding four k.sub.z levels that result in four z-pixels in die excited slab after Fourier transformation in the z direction (N.sub.z =4). N.sub.2 and the retained slab thickness may be reduced slightly after acquisition if edge slices are dropped from each 2-k.sub.z -k.sub.y data set to minimize the effect of imperfections in the slab profile. It is understood that the optimal imaging area 108 is defined by the physical characteristics of the MRI system 10. It is preferred to define a volume of interest, or slab, 114 to be within the optimal imaging area 108.

Detailed Description Text (10):
It is Doted that when N.sub.z =N.sub.wf, each of the table increments throughout the desired FOV 110 arc of equal distance. Accordingly, any of the aforementioned parameters con be adjusted as desired. That is, the slab thickness, 112 may be made larger or smaller, or the number of table positions and data acquisition sets 106

can be increased or decreased, above or below the 16 that are shown. The minimum number of table positions desired to reconstruct an image is equal to the number of waveform subsets, N.sub.wf. Additionally, the number of z-pixels, N.sub.z, retained in each excited slab, as well as the number of k.sub.x -k.sub.y subsets can be modified as desired. Preferably however, N.sub.z is kept greater than or equal to N.sub.wf. One such modification will be described with reference to FIG. 3.

Detailed Description Text (13):
For complete sampling, the number of z-pixels retained, N.sub.z, must be at least equal to the number of k.sub.x -k.sub.y waveform subsets, N.sub.wf. However, referring to FIG. 3, which also illustrates a simple example assuming table motion in the z direction, increasing the slab thickness 132 while maintaining the z resolution results in an increase in the number of z-pixels, N that are encoded at each table position. In this example, N.sub.z =8 for 4 k.sub.x -k.sub.y subsets (N.sub.wf =4). Because N.sub.z is greater than N.sub.wf, the table increments are not all equal, as shown in FIG. 2. That is, the distance between table positions 1, 2, 3, and 4, is less than that between table positions 4 and table position 5. Therefore, using a thicker slab, fewer movements of the table are required for the same spatial coverage. This results in an overall faster acquisition for the same size FOV, as compared to that in FIG. 2, if the time to initiate table motion is long relative to the time for a single acquisition. Even though increasing the slab thickness, N.sub.z, incrementally increases individual acquisition time for each slab, the total scan time decreases because the time to initiate table motion dominates. Thus, in the case when the time to initiate table motion is long relative to the time for a single acquisition, scan time is minimized by minimizing the number of table movements. With current equipment, it typically takes approximately one second to initiate table motion. While reducing this time is the long-term desired solution, it is not practical in the short term since it requires significant changes to the system architecture.

Detailed Description Text (15):
To generalize, the table step distances are multiples of the pixel size in the direction of table motion and are selected to ensure complete sampling of the 3D matrix. The number of table steps required depends on the relative number of pixels retained in the excited slab, N.sub.z, for the case of motion in the z direction, and the number of magnetic field gradient waveform subsets required to fully encode the dimensions perpendicular to table motion, N.sub.wf. As previously indicated, for complete sampling, N.sub.z should be at least equal to N.sub.wf. However, if N.sub.z is greater than N.sub.wf, faster overall scan times are achievable. It is noted that the subsets of magnetic field gradient waveforms, (g.sub.x g.sub.y) are defined by one or a series of such waveforms that differ between subsets. This set, or series, of magnetic field gradient waveforms, that encode the k.sub.x, k.sub.y subsets, are then repeated in a cyclic manner to obtain the data sets 106, FIG. 2, and 134, FIG. 3.

Detailed Description Text (17):
FIG. 4 is a flow chart for a data acquisition sequence in accordance with the techniques of FIGS. 2 and 3. After the data acquisition sequence is initialized 140, the table is positioned at the first location of the desired FOV and a variable i is initialized 142. MR data is acquired by repeatedly exciting spins using an RF pulse and applying magnetic field gradient waveforms to encode the volume of interest 144. Assuming table motion in the z-direction, all k.sub.z data are acquired for the selected k.sub.x -k.sub.y subset, that are in the dimensions perpendicular to table motion 146. The spatial extent in the direction of table motion is restricted using a restriction method such as either a slab-selective RF excitation or by acquiring data in such a way that the acquisition filter can be used to restrict the slab thickness. It is noted that for phase encoding in the direction of table motion the RF pulse is repeatedly applied prior to each acquisition 147 until all k.sub.z data is acquired 146. For readout in the direction of table motion, each RF pulse is applied at 144 followed by acquisition

of complete k.sub.z data for the selected k.sub.x -k.sub.y subset 146. As long as the end of the FOV is not reached 148, 150, the variable i is incremented 152 and the system checks whether a complete set of magnetic gradient field waveform subsets has been acquired 154. That is, as long as the variable i is not an even multiple of N.sub.wf 154, 156, the table is moved a distance equal to the resolution in the direction of table motion 158, and the next slab becomes the current slab at 144 and data is again acquired at 146. After a complete series of subsets have been acquired 154, 160, the system determines if the next table increment is in accordance to that described with reference to FIG. 2 or FIG. 3. That is, if the number of magnetic gradient field waveforms is equal to the number of pixels retained in the slab in the direction of table motion (N.sub.wf =N.sub.z), the table is moved a distance equal to the z-resolution, or in the direction of table motion 162, as in FIG. 2, and the data acquisition sequence continues 144, 146. Otherwise, where N.sub.z is greater than N.sub.wf 162, such as in FIG. 3, the table is moved a distance according to:

Detailed Description Text (24):
Additionally, the present invention also includes a computer program to control a medical image scanner and create images across scanning boundaries without boundary artifacts. The computer program has a set of instructions to control a computer to select an FOV spanning an area greater than a predefined optimal imaging area of the medical image scanner and acquire MR data by repeatedly applying an RF pulse to excite a region in the selected FOV and magnetic field gradients to encode the region in a direction. The instructions further control the computer to apply a k-space trajectory to encode the region in the direction of table motion and acquire data for a subset of a second and third direction. The computer program includes instructions to reposition the predefined optimal imaging area with respect to an imaging object and repeat the image data acquisition and the imaging area incremental reposition until complete image data are acquired across the entire FOV to reconstruct an image of the FOV.

Current US Cross Reference Classification (2):
600/415

CLAIMS:

4. The method of claim 1 wherein the first direction is in a direction of the step-wise movement and is defined as in a z-direction and a number of image pixels obtained within the selected slab thickness in the z-direction is at least equal to a number of k.sub.x -k.sub.y subsets.

21. The MRI apparatus of claim 18 wherein the computer is further programmed to: apply a slab-selective RF pulse to excite a volume of interest in the z-direction; apply a 3D k-space trajectory to encode the volume interest; and wherein the MR data acquired in the z-direction has a number of pixels that are at least equal to a number of k.sub.x -k.sub.y subsets.

22. The MRI apparatus of claim 18 wherein the computer is further programmed to: apply an RF pulse to excite a volume of interest; apply a 3D k-space trajectory to encode the volume of interest; filter the acquired MR data to restrict the MR data to the defined fixed slab; and wherein the MR data acquired in the z-direction has a number of pixels that are at least equal to a number of k.sub.x -k.sub.y subsets.

28. A computer program to control a medical image scanner and create images across scanning boundaries without boundary artifacts, the computer program having a set of instructions to control a computer to: select an FOV spanning an area greater than a predefined optimal imaging area of the medical image scanner; apply an RF pulse to excite a region in at least a first direction in the selected FOV; apply magnetic field gradients to encode the region in the first direction; acquire 3D k-

space data in the first direction for a subset of a second and third direction; reposition the predefined optimal imaging area, with respect to an imaging object, an incremental step; repeat data acquisition and the imaging area incremental reposition until complete image data are acquired across the entire FOV to reconstruct an image of the FOV.

32. The computer program of claim 28 wherein the 3D k-space data is acquired in z for a subset of k.sub.x -k.sub.y, and wherein the 3D k-space data acquired in z has a number of pixels that is at least equal to a number of k.sub.x k.sub.y subsets.

34. The computer program of claim 28 having further instructions to maintain a position of a slab thickness fixed, relative to a magnet of the medical image scanner, during the imaging of the desired FOV and while repositioning the imaging area.

36. The computer program of claim 28 wherein the first direction is a z-direction and the 3D k-space data includes MR data, and the MR data acquired in the z-direction is represented in a number of retained pixels, the number of which is greater than a number of k.sub.x -k.sub.y subsets, and wherein the RF pulse is continually applied to maintain a steady-state but where MR data is not acquired during table movement, and wherein the magnetic field gradients encode a 3D trajectory that is uniform in k.sub.z.

Previous Doc Next Doc Go to Doc#

L22: Entry 3 of 3 File: USPT May 6, 2003

DOCUMENT-IDENTIFIER: US 6560476 B1
**** See image for Certificate of Correction ****
TITLE: Evaluating disease progression using magnetic resonance imaging

Detailed Description Text (4):
The processing subsystem 14 includes a database 24 that is operatively connected to the MRI acquisition system. The operative connection between the MRI acquisition system and the database can take different forms, such as a network connection or a dedicated fiber-optic link. It may also take the form of an intermittent connection, such as an e-mail link, or a physically transported high-capacity storage medium, such as an optical disk. The database can range from a collection of files for smaller research systems to more powerful and feature-rich databases for systems configured to process data for larger numbers of patients. Also included in the processing system are a segmentation module 26, a sub-pixel processing module 28, a biparametric fitting module 30, a biparametric mapping module 32, a three-dimensional cartilage image gereration module 34, a signal analysis module 36, a difference mapping module 38, and a display 39. These can all be operatively connected to the database such that they can access raw data sets received from the acquisition subsystem 12, as well as different processed versions of these data sets. Each of these modules can be implemented using special-purpose hardware, software running on a general-purpose processor, or a combination of both. In addition, while the system can be broken into the series of modules shown in FIG. 1, one of ordinary skill in the art would recognize that it is also possible to combine them and/or split them to achieve a different breakdown. In one embodiment, the modules and database are part of a larger software system that runs on one or more workstation computers outfitted with an operating system such as Microsoft's Windows.RTM. 9X or Windows NT.RTM. operating system.

Detailed Description Text (21):
A grid is defined on the fitted biparametric primitive surface in order to derive a new representation for the contour points. All contour points are first orthogonaly projected on the grid surface. Each three-dimensional contour point (xi, yi, zi) in the imaging coordinate system is mapped to a corresponding coordinate on the grid (column, row, offset). The result can be seen as an offset map where the pixel intensity is a distance to the primitive.

Detailed Description Text (23):
Referring to FIG. 10, the system obtains new images of the cartilage based on the biparametric surface coordinate systems derived for the data (step 56). This process results in a layered representation of the cartilage that is akin to the structure of an onion. Each cartilage slice 150a, 150b . . . 150n presents the intensity image obtained by extracting all pixels located at an isometric distance 152 from the bone surface. The operator can move through these slices, allowing him or her to see the effects of the disease on different levels of the bone and cartilage.

Detailed Description Text (24):
The sub-pixel accuracy processing module 28 uses these new three-dimensional images

and the offset image map of the bone surface to obtain a three-dimensional sub-pixel representation of the bone surface. This process improves the accuracy of the first image surfaces and subsequent operations performed on them.

Detailed Description Text (25):
The signal analysis module 36 also applies two signal processing methods (step 60) to the new three-dimensional images (from step 56). The first of these is a textural analysis of the cartilage pixel organization in the cartilage slices (from step 56). The second is local signal density analysis of the cartilage that can be displayed as a "cartilage radiograph" used to find local hypo-signal regions.

Detailed Description Text (26):
The system then generates a display mapping for the cartilage (step 62). For comparison purposes, the cartilage is mainly represented by two maps. The first is a volume image map where each pixel represents a local volume localized on a 300 micron.times.300 micron surface, and the second is a thickness image map where each pixel represents a local mean thickness localized on a 300 micron.times.300 micron surface. A third map is used as a mask map that defines one or more topo-anatomical regions. This mask map is uses to obtain local thickness or volume.

Detailed Description Text (33):
This process is performed by a robust least square minimization of the difference in combination with a surface filtering of the new image data to the sub-pixel level. Once the bone biparametric surface has been fitted in the new MR image sets of the same patient, the new Cartilage-synovium interface is segmented in a manner that is similar to the first cartilage segmentation step. A new biparametric surface can then be derived for the deformation of the cartilage (step 72). The data set resulting from this step expresses the difference between the two surfaces.

Current US Cross Reference Classification (2):
600/415

Other Reference Publication (3):
"Adaptive Template Moderated Spatially Varying Statistical Classification [of anatomy] (Abstract)", Warfield et al., Medical Image Computing and Computer-Assisted Intervention--MICCAI'98, First International Conference. Proceedings pp. 431-438, 1998.

Other Reference Publication (13):
"Deformation Analysis To Detect And Quantify Active Lesions in Three-Dimensional Medical Image Sequences" Jean-Philippe Thirion, et al., Ieee Transactions On Medical Imaging, May 5, 1999.

Other Reference Publication (35):
"An Algorithmic Overview of Surface Registration Techniques for Medical Imaging" Michel A. Audette, et al., Medical Image Analysis 4 (2000).

Previous Doc Next Doc Go to Doc#